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Transition from Research to Operations: ARKTOS - A Knowledge-Based Sea Ice Classification System

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Abstract

ARKTOS is a fully automated intelligent system that classifies sea ice and that is now being used by the U.S. National Ice Center (NIC) for daily operations related to the NIC's task of mapping the ice covered oceans. In this paper we describe the process of taking a research project and transitioning it to an operational environment. We discuss the theoretical methodologies implemented in ARKTOS, and how ARKTOS was developed, tested, and finally moved to operations.

HISTORY

The U.S. National Ice Center (NIC), under sponsorship of the U.S. Navy, U.S. Coast Guard, and National Oceanic and Atmospheric Administration (NOAA), is tasked with mapping the ice covered oceans of the world using both remotely sensed and in situ observations. Synthetic Aperture Radar (SAR) data became a major input to the program of the NIC soon after the November, 1995 launch of the Canadian RADARSAT satellite [1]. The Alaska SAR Facility (ASF) at Fairbanks provides RADARSAT data to the NIC. The NIC also acquires limited amounts of imagery under contract from Tromso, Norway and West Freugh, Scotland, and from the Gatineau station mask through a bilateral data exchange agreement with the Canadian Ice Service (CIS). In order to make efficient use of the 0.8 GB per day of data currently received, the NIC has been actively involved in the development of systems that can assist in analysis of ice conditions using SAR.

The University of Kansas (KU) began to study the use of expert systems in sea ice classification from SAR under a NASA graduate student fellowship in 1990. The work was extended in 1992 and 1993 under a NASA Mission to Planet Earth grant and produced various techniques to measure and identify sea ice features in SAR imagery [2,3]. Of particular interest to the NIC was a system to classify winter sea ice into three major classes using dynamic thresholding and expert, rule-based systems. A research to operations development cycle was identified, and appropriate contributions from both the research and operational community were identified.

THE ARKTOS SYSTEM

The ARKTOS (Advanced Reasoning using Knowledge for Typing Of Sea ice) system is a sea ice classification system that incorporates image processing and knowledge based rules to interpret RADARSAT SAR images. As shown in Fig. 1, ARKTOS first segments the input image using Watershed region growing technique based on image gradients, and subsequently merges regions based on area, average intensity, and strength of common boundaries [5].

ARKTOS then computes attributes for each contiguous region (henceforth, feature) such as area, average intensity, and shape and texture measures. Given these measurements, facts regarding each feature are formed by quantizing the values into symbols. For example, if the feature's average intensity is less than 50.0, then intensity (feature) = "black". The decision points (or thresholds) were determined and refined via visual inspection of features. Next, during the classification phase, the Dempster-Shafer rule-base engine reads the facts and matches rules by looking for satisfied conditions. After matched rules are fired, the engine combines the evidence and gives the belief and plausibility values for a feature to be in one of four surface types: multi-year ice, first–year ice, open water and unknown. Finally, ARKTOS assigns the feature to the surface type with the highest product of the plausibility and belief values.

NIC REFINEMENT OF ARKTOS

The first phase of work at NIC involved the identification of geophysical parameters and geographic regions of importance to the operational sea ice community. As goals for system output became well defined, work proceeded toward the refinement of the original KU system. It was decided that initially, the system would be designed to operate in only the Beaufort and Chukchi Seas. A series of knowledge engineering experiments were designed and KU conducted multimedia interviews (oral, computer-based and image-based) with sea ice geophysicists from both the NIC and CIS. These interviews were then transcribed and the high-level semantics were converted to measurable descriptors [4]. An improved segmentation scheme was devised that uses a Watershed region growing technique based on image gradients, and subsequently merges regions based on area, average intensity, and strength of common boundaries. The system was tuned to accept the operational flow of RADARSAT SAR images routinely in use at both NIC and CIS. A beta version of ARKTOS was delivered to NIC and the Naval Research Laboratory, Stennis Space Center (NRLSSC), in March of 1998.

Initial work involved fine tuning of the segmentation algorithm, accomplished through an iterative process between KU and NIC. It was found that the output was best when the image was subjected to a 5 x 5 Gaussian mask average routine prior to segmentation. The averaging routine was carefully implemented to maintain the distribution of pixel values found in the original image. Due to the strict time constraints found in an operational environment, much work was done to optimize the system performance. Currently ARKTOS runs under 3 minutes per RADARSAT ScanSAR image (about 500x500 km^2) on a Pentium II running NT.

At the Naval Research Laboratory, Stennis Space Center, a test data set of 28 images was selected that spanned the October 1997 to May 1998 time frame and covered ice types and conditions normally found in the Beaufort and Chukcki Seas. Using this test data set, sea ice experts refined the feature attributes and rule base to correct misinterpretations introduced during the knowledge engineering process. This work was facilitated by the delivery of a JAVA-based GUI that allows expert users to view the results of all the stages of the process, from segmentation, to feature extraction, to classification. Ancillary data, including NASA Team algorithm ice concentration fields from the Special Sensor Microwave/Imager (SSM/I), a land mask and manually derived ice chart information, were added to the system. Rules were developed to exploit these new information sources. An example of how the fusion of different data sources improves classification is shown in Fig. 2.

CURRENT STATUS

The current version of ARKTOS is designed to operate in the Beaufort Sea in all seasons. All testing has been concluded and the classification accuracy of the system makes it acceptable in an operational environment. Work is now proceeding to develop a display methodology that is compatible with the current operational work flow. The system will be fully transitioned to the NIC operations floor by the summer of 1999.

FUTURE WORK

Future work will involve the addition of rules based on climatological ice conditions and extension of ARKTOS to new geographic regions and to new data streams, including ENVISAT and other future SAR sensors.

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ACKNOWLEDGMENTS

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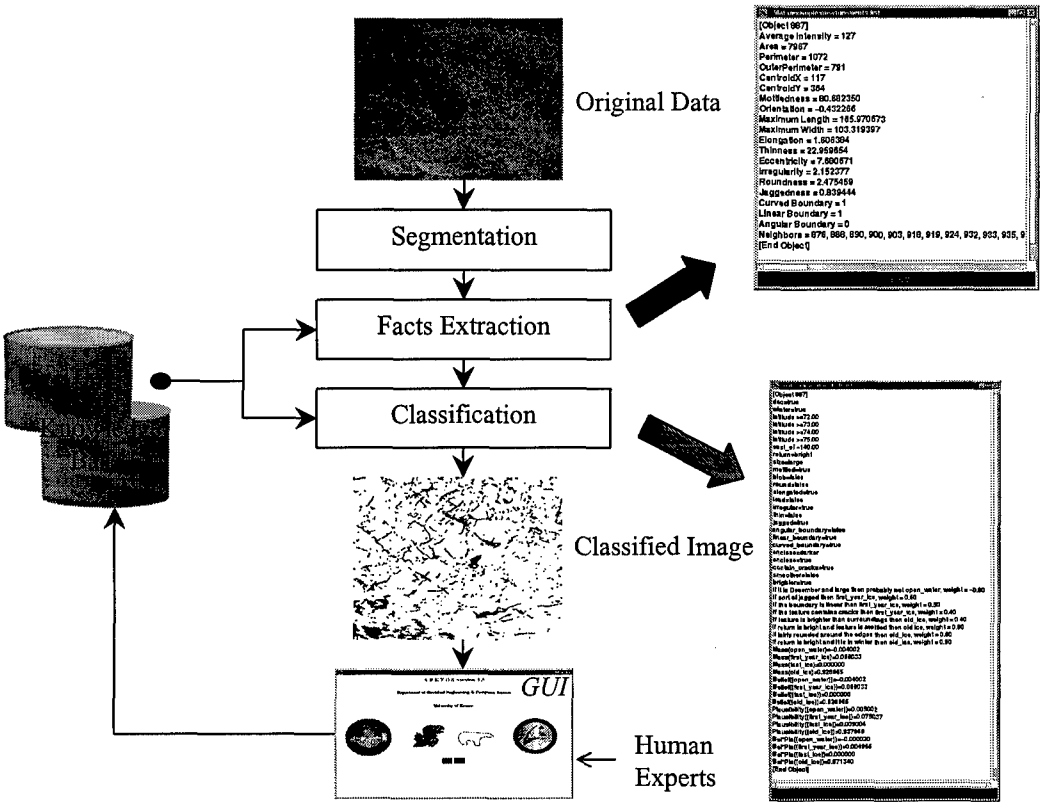

Figure 1. ARKTOS system flow chart.

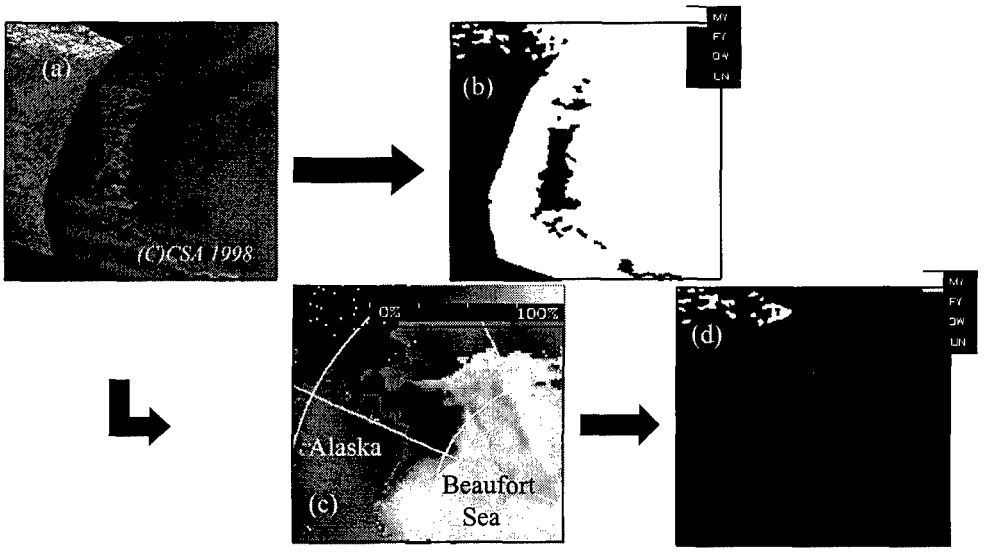

Figure 2. Improvements gained through addition of SSM/I ice concentration data. (a) Radarsat image near Point Hope, Alaska. (b) ARKTOS classification map (without SSM/I), incorrectly classifying water as MY ice (c) SSM/I (d) After incorporation of SSM/I, ARKTOS classification with water correctly classified.